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Ecotoxicological effects on *Lemna minor* and *Daphnia magna* of leachates from differently aged landfills of Ghana

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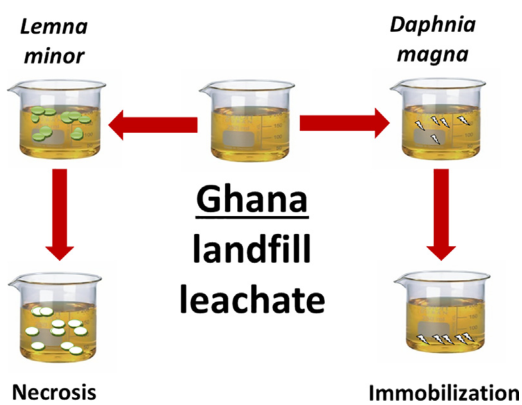
HIGHLIGHTS

- The landfill leachates investigated were highly toxic to the aquatic organisms.
- Proper decommissioning of the landfill site helps in reducing the toxicity of the rain leachate.
- The leachate from the oldest landfill was the most toxic to the aquatic organisms.
- Youngest leachate more toxic to Daphnia and oldest leachate more toxic to duckweed.

GRAPHICAL ABSTRACT



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ABSTRACT

Management of leachates generated by solid waste disposal is a very challenging aspect of landfill management in most parts of the world. In most developing countries, the leachates generated are discharged into the environment without treatment, leading to contamination of ground and surface waters and causing human health problems. Even though its potential risk has been established through chemical analyses, less work has been conducted on its effect on ecosystems. This study assessed the toxicity of leachates from three landfill sites of different ages from Ghana, namely Tema, Mallam and Oblogo, to aquatic organisms. Duckweed (*Lemna minor*) and crustaceans (*Daphnia magna*) toxicity tests were performed using exposures to concentrations of 6.25, 12.5, 25, 50 and 100 mL/L of the landfill leachates in control growth media. Physico-chemical properties of the leachates were also determined. The leachates from all the sites were toxic with IC 50 values ranging from 2.8 to 29.5%. The Oblogo landfill leachate (the oldest site) being most toxic to duckweed and Tema landfill leachate (the youngest site) most toxic to *D. magna*. Leachates characterized had varying concentrations of heavy metals (0.2–42.3 mg/L) with Cu and Cd below detectable limit. The organic component COD was below the permissible level (110–541 mg/L) and the TOC exceeded the permissible level (350–6920 mg/L). These results indicate that the age and other characteristics of the landfill sites contribute to the difference in the toxicity of the Ghana landfill leachates.

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1. Introduction

Solid waste management is a great challenge in most developing countries because of the nature of waste materials deposited into the landfills. Most of these wastes contain hazardous substances and may have negative effects on the environment (Assmuth and Strandberg, 1993; Chiang et al., 1995). When wastes are landfilled, they undergo series of physico-chemical and biological transformations when making contact with liquid, generating highly contaminated wastewater called leachate. The landfill leachate may become toxic depending on the nature of the waste landfilled. The leachate generated from solid waste poses many challenges to the environment depending on the leachate management established at the site. However, landfill leachate management is a great challenge in developing countries because most of the landfill sites constructed for receiving solid waste do not have a proper leachate treatment facility. As a consequence, the leachate produced may impact surface and groundwater resources and human and ecosystem health (Schrab et al., 1993).

In most developing countries, such as Ghana, landfill management is the preferred option for solid waste disposal, and most of landfills are open dumps which do not have any proper leachate management systems. This poses environmental hazards to plants and animals because the leachates are directly released into the environment without treatment (Mwiganga and Kansime, 2005). The leachate released from the Oblogo landfill site contains high concentrations of nutrients and heavy metals such as iron, zinc and aluminum (Osei et al., 2011). Landfill leachates may contain high concentrations of organic and inorganic pollutants, which may be toxic to the environment (Kettunen and Rintala, 1998). Maitia et al. (2016) reported that landfill leachate affected surface and groundwater quality. And according to Nyame et al. (2012), discharges of landfill leachate could negatively affect the Ramsar Densu wetland and surrounding water bodies and nearby ecosystems.

Aik et al. (2010) showed that landfill leachate quality is affected by the age of the waste due to bacterial growth and chemical reactions. According to Adhikari and Khana (2015), the age of landfills has serious effects on leachate composition and hence its impact on aquatic organisms. The age of the landfill together with other characteristics such as climatic conditions, waste composition, volume and concentration of biodegradable matter, determine the chemical composition of the leachate (Im et al., 2001; Chu et al., 1994). Simple chemical analyses has been the main method for determining the potential risk of landfill leachates in Ghana, but it may not be able to detect low concentrations of pollutants nor may it allow predicting their potential mixture effects. Chemical analyses therefore may underestimate the toxicity of Ghana landfill leachate (Thomas et al., 2009). Hence, the application of biological assessments is now the recommended method for determining the toxicity of leachates to the environment. This paper seeks to assess the level of toxicity of Ghana landfill leachate from three landfill sites of different ages, using aquatic plants (*Lemna minor*) and crustaceans (*Daphnia magna*).

There are varying methods available for assessing the toxicity of landfill leachate: Bacteria (*Vibrio fischeri*), invertebrates (*Daphnia magna*, *Artemia salina*), microalgae (*Desmodemos subspicatus*), fish (*Carassius auratus*), plants (*Lemna minor*, *Hordeum vulgare*) and mammals constituting different trophic levels as test organisms. Here, *D. magna* and *L. minor* have been selected for this research because they are simple, fast, cost effective, easy to use and such combination or battery has not been used for testing toxicity of landfill leachate. Also, they represents plants and animals which will give a very good information concerning the impact of leachate on the ecosystem. The organisms selected will really help in the determining the toxicity of the leachate, because research that they have been used had proven potential toxicity of the wastewater. The other organisms were not considered because of the focus of the research.

The landfill leachates were collected from three different waste disposal sites in the Greater Accra Region in Ghana. Such a research has never been done in Ghana before and the results will help policy makers to better understand the impact of discharging untreated landfill leachate to water bodies and natural ecosystem.

2. Material and method

2.1. Sampling sites

The Oblogo Landfill Site (OLS) is an abandoned stone quarry pit which was used as a dumpsite (Fig. 3). There was no engineering works done to ensure protection of the underground and surface water resources. Oblogo is located in the Greater Accra region, approximately 12.8 km away from the capital city, Accra. The operation of the site started in late 2002 and was managed by the Accra Metropolitan Assembly. It received all the waste generated within Greater Accra with an estimated daily collection of 2500 metric tons and operated for more than six years. After closing the operations, the site was not decommissioned properly, which allowed more leachate to be generated whenever it rained. The OLS was located close to the Densu River which serves the greater part of Accra City region.

The Mallam SCC Landfill Site (MLS)is an abandoned stone quarry pit which was used as a dumpsite without any proper engineering works (Fig. 2). Before the disposal of waste began, the pit was lined with clay material, creating temporal sump to capture the leachate and provided with a drainage system to manage the leachate when there was over flow of leachate from the site into the main drains. The MLS is located in the Greater Accra region in the Ga West Municipal Assembly and located approximately 14.9 km from Accra. Zoomlion Ghana company managed the site and operations began in late 2008 after the closure of the Oblogo landfill site. The MLS received a daily waste capacity of 2500 metric tons and operations lasted for 2 years. This site was located adjacent to the Mallam 1 & 2 landfill sites, which were decommissioned >6 years before the operations began at Mallam SCC. This made the operations of the MLS quite challenging, as there was already a lot of environmental pollution. The site was capped with support of a donor grant from the World Bank in 2014 to reduce the nuisance that comes with the closure of a landfill site.

The Tema landfill site (TLS) is the first engineered landfill site in Greater Accra region and constructed to receive waste within the Tema vicinity with a total daily capacity of 300 metric tons (Fig. 1). However, due to the lack of landfill sites in Accra, the daily capacity increased to 1200 metric tons. The TLS is located 25 km east of the capital city, Accra, in the region of Greater. As of 2013, Tema is the eleventh most populated settlement in Ghana, with a population of approximately 162,000 people. Operations at the site started early 2013,with Zoomlion Ghana limited and the Tema Metropolitan Assembly managing the site. The TLS is currently in operation and it has an anaerobic leachate management system. The treatment of the leachate is still of great challenge to the extent of leachate flowing into nearby community and water bodies.

2.2. Sampling and analytical procedures

Leachates were collected from the sumps constructed to capture leachate generated from the sites, with the exception of the Tema landfill site where samples were collected from the maturation pond. Samples were collected during the dry season to avoid any dilution of the leachate content by rain water. The samples were preserved on ice to prevent any biochemical reactions. The pH and conductivity of the leachates were determined using the WTW Multiline P4, Germany under laboratory conditions. The Chemical Oxygen Demand (COD) was determined using EPA (1973).The Total Organic Carbon (TOC) was determined using the high temperature combustion method, because it is suitable for samples with high levels of TOC that will require

Fig. 1. The Oblogo site showing a compactor truck tipping waste and the bulldozer pushing the waste with some scavengers picking some materials from the waste.

dilution. Atomic Absorption Spectrometry (AAS) (SensAA GBC Scientific Equipment Dual, Australia) was used to determine elements present in the landfill leachates.

2.3. Ecotoxicological bioassays

The duckweed aquatic plant toxicity test used *Lemna minor* (strain Steinberg, origin: Federal Environment Agency (FDA), Berlin, Germany), which was cultivated in an incubator under at 24 ± 2 °C and light cycle (16 h/8 h; light/dark; 5000–6000 lx) for 7 days. The growth (control) medium, Steinberg with pH 5.5 ± 0.2, was prepared according to ISO guideline 20079 (ISO, 2005). The test was carried out in 150 mL beakers. Three replicates of 100 mL of control medium and 100 mL of samples were prepared at different leachate concentrations (6.25; 12.5; 25; 50 and 100 mL/L). An initial frond number of ten was put into each replicate and the beakers were covered with transparent film. The samples were incubated for 168 h under the same temperature and light conditions as the culture. The plants were photographed at the beginning (0 day), middle (3 days) and end of the exposures (7 days) for frond area and chlorophyll estimation. After the 7 day exposures, the chlorophyll content was extracted in 99.8% methanol (48 h; 4 °C, dark) and measured by spectrophotometry (Hach, DR/2400, Germany). The calculation of the total chlorophyll content was made according to Wellburn (1994). The frond number and area were calculated by image analysis *NIS Elements ver. 4.2*, 2014.

The *Daphnia magna* acute mobility inhibition assay was performed using juvenile individuals of *Daphnia magna* Straus aged up to 24 h, originating from ephippia (Microbiotests Inc., Mariakerke (Gent), Belgium). The test design was based on ISO guideline 6341(ISO, 2012). Aerated ADaM medium (pH ~ 7.8 ± 0.2; O_2 ≥ 7.0 mg/L) according to Klüttgen et al. (1994) was used as a control. Five juveniles were placed into 25-mL-beakers filled with 25 mL of sample or control medium to reach leachate concentrations of6.25; 12.5;25;50; 100 mL/L. The beakers were covered with transparent film and incubated at24 ± 2 °C and a 16 h/8 h light/dark cycle (2000–3000 lx). Three replicates were used. The mobility (viability) of the test organisms was observed after the 48 h-exposure.

2.4. Data analysis

Analysis of dose-response curve and calculation of IC50 values were attained by non-linear regression (logit model) using log transforming the concentrations values on the X-axis; normalization of the values of percentage inhibition on the Y-axis and the fitting of dose-response curves all using the GraphPad Prism ver. 5.01 (2009). The used

Fig. 2. The Mallam capped site showing the peripheral drains to capture leachate into the sump at the far right end of the picture with barb wires to deter people from entering into the site.

Fig. 3. The Tema landfill site showing the aerial view of the site and the leachate pond at the far right of the picture where the leachate sample collected.

mathematical equation was:

$$y = \frac{1}{1 + \exp\left[b\log\left(\frac{IC50}{X}\right)\right]} \tag{1}$$

3. Results and discussion

3.1. Landfill leachate characteristics

Leachate sample colours were orange brown or dark brown and the leachates had a pungent smell because of the presence of organic acids. This is associated with the high amount of degrading organic matter in the leachates. Aziz et al. (2007) also reported a similar process in their colour removal from landfill leachate. The colour of Mallam and Oblogo leachates were dark brown, which was due to high level of dissolved organic matter. Usually this occurs because of presence of fulvic and humic acids (Bashir et al., 2010).The pH of the leachates differed according to the age of the landfill and was generally between 7.8 and 9.0 (Table 1). The samples analysed were not different from the generally acceptable pH range: Tema (TLS) 9.4, Mallam (MLS) 8.2 and Oblogo Landfill Site (OLS) 7.8 (Table 1). However, the pH of the TLS was higher than the range of intermediate aged landfills, which is 6.5–7.5 (Renou et al., 2008) because of the percolation of leachate from the acidic phase through the matured waste. This triggers methanogenic activities, which leads to the increase in pH. Trankler et al. (2005) confirmed this by showing seasonal changes in the characteristics of leachates. The conductivity of the leachates (Table 1) was generally very high, which indicates that all landfills contained high concentrations of ions, and this can affect organisms in any water body to which these leachates are released without treatment.

The Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC) levels were determined because they are of importance for the quality of wastewater. In addition, most literature has mentioned the possibility of replacing COD determination with TOC measurements in water quality assessments (Dubber and Gray, 2010). The COD of the leachates ranges between 110 and 541 mg/L and levels in Tema and Oblogo sites were below the permissible limit by 2 times and <1 times respectively. However, the leachate from Mallam site was above the permissible level by 2 times (Kurniawan et al., 2010). However, the leachate from Mallam site was above the permissible level by 2 times (Kurniawan et al., 2010). The MLS leachate had the highest COD, which indicates that it contained more organic matter than the other leachates. This could be largely due the type of waste disposed at the landfill. Interestingly, all the leachates analysed showed high levels of TOC which were all above the permissible limit which ranges between 350 and 6920 mg/L. The leachates TOC assessed, the Tema site was 87 times, Mallam site 11 times and Oblogo 4 times above the permissible level (Kurniawan et al., 2010). This indicates that the carbon concentrations in the leachates were very high, potentially causing a threat to surface water when discharged without treatment as it will trigger

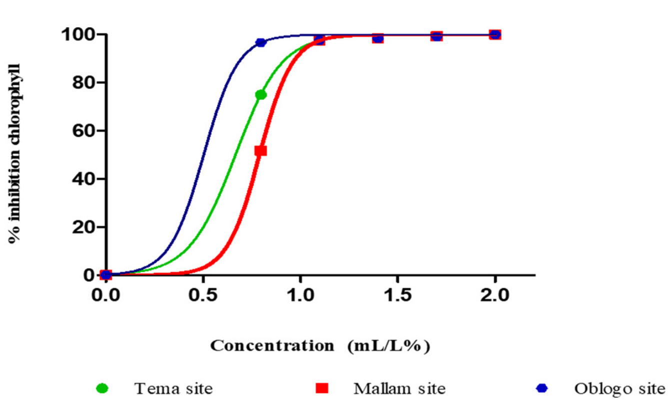

Fig. 4. Percentage inhibition growth rate of the frond area of duckweed (*Lemna minor*) upon exposure to dilution series of leachates from the Tema (TLS), Mallam (MLS) and Oblogo (OLS) landfill sites in Ghana.

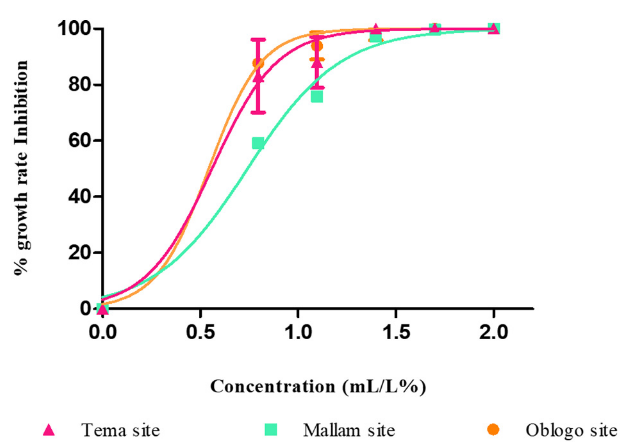

Fig. 5. Percentage inhibition of Chlorophyll content of the duckweed (*Lemna minor*) fronds upon exposure to dilution series of leachates from Tema (TLS), Mallam (MLS) and Oblogo (OLS) landfill sites in Ghana.

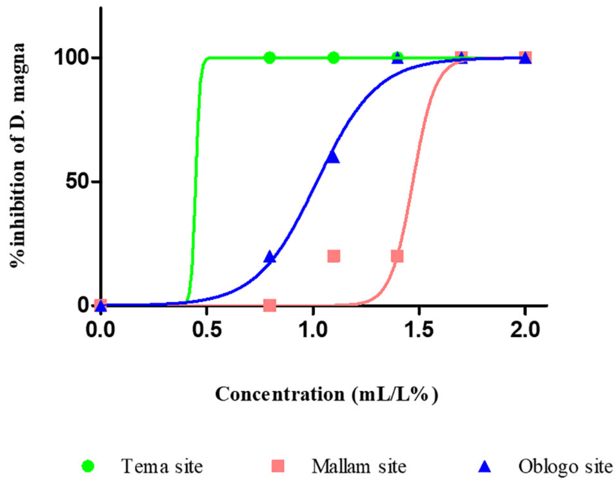

Fig. 6. Percentage inhibition of *Daphnia magna* following 48 h exposure to dilution series of leachate from the Tema (TLS), Mallam (MLS) and Oblogo (OLS) landfill sites in Ghana.

unlimited growth of microorganisms creating anoxic conditions lethal for aquatic organisms. There was higher TOC values than that of COD. The reason could be due to non-oxidizing organic compounds and also because the wood contain less hydrogen atoms the was less consumption of oxygen which might be the caused the low values of COD. Also, some ions might not have been oxidized such Phosphorus and Potassium.

Low concentrations of ammonia (NH_3) generally were observed in younger landfills. As the landfill ages the concentration of biodegradable organic compounds decreases and the concentration of ammonia increases (Lou et al., 2009). The leachates investigated in this study showed similar trends (TLS-120 mg/L, MLS-610 mg/L and OLS-3160 mg/L) with the leachate from the youngest landfill site (TLS) having the lowest ammonia concentration. The leachates from all three sites were above the permissible range of ammonia even though are not in toxicity level, but are detrimental and inhibitory to aquatic organisms. The oldest landfill (OLS) can be harmful to biological processes as its ammonia concentration was above 3000 mg/L (Kurniawan et al., 2010).

Heavy metals identified were Ni, Pb, Fe, Mn, Cr and Zn (Table 2). Concentrations exceeding the permissible level for discharge into surface water (World Health Organization, 2011) were found for Cr, Ni, and Pb in all the leachates, and for Zn and Fe in the leachate from MLS landfill. Cd and Cu were not detected in any of the leachates and Pb was absent in Oblogo landfill leachate. Osei et al. (2011) did find Cd, Cu and Pb in Oblogo landfill leachate, which confirms that heavy metal concentrations in landfill leachate may reduce with aging. Sorption and precipitation processes could explain for the absence of these metals as they reduce their dissolution (Statom et al., 2004).

3.2. Ecotoxicological assays

3.2.1. Duckweed toxicity

The growth rate of duckweed in the leachates was determined using frond numbers (pcs), frond area (cm^2) and chlorophyll content (μg/L). Generally, there was no increase in frond numbers at the higher leachate concentrations, but an increase of frond numbers occurred at 6.25 and 12.5 mL/L for all three leachate samples. The reproduction of fronds in the leachate occurred within the first 3 days, afterwards no reproduction was detected but rather chlorosis of the fronds. This might be due to reduction in the nutrients required for plant growth within the experimental setup, which did not involve renewal of the test solutions. The low ammonium content in the leachates might have contributed to a lack of nitrogen (Iqbal and Baig, 2017).

The growth rate based on the increase of the frond areas exhibited similar trends to that of the frond numbers. The MLS leachate showed the highest growth rate, the leachate from the OLS site the lowest at concentrations of 6.25 and 12.5 mL/L, but in all cases the growth rate was <50% of that in the control (Fig. 4). At leachate concentrations of 25, 50 and 100 mL/L, there was no growth of frond areas. The growth effect could be due to the high electrical conductivity measured in all landfill leachates (Iqbal et al., 2017) (Table 1). The presence of ions could greatly contribute to the growth rate inhibition, by affecting the plant-specific absorption of ions and build-up of osmotic pressure around the roots (Wendeou et al., 2013). In addition, the heavy metals detected in the leachate at concentrations above the permissible levels could have contributed to the inhibition in frond growth. Metals including lead, nickel and zinc have proven to affect *L. minor* at concentrations equivalent to those found in landfill leachates (Dirilgen and Inel, 1994). The presence of Pb, Cr and Zn in the leachate may have contributed to the high growth inhibition, because they could affect cellular metabolism (Singh et al., 2008). The growth rate inhibition could also be due to the high pH of the samples (Fig. 4). The fact that growth inhibition was smallest for the MLS leachate might be due to its pH being within the optimal range of 4.5 and 8.3 for duckweed survival (Environment Canada, 1999).

The IC50 was low for all three leachates analysed, and lowest in the Oblogo landfill leachate with an IC50 of 3.1% (Table 3). This indicates the older the landfill the more toxic the leachate becomes.

The chlorophyll content of the fronds was very low at all the concentrations, which confirmed the low growth in the frond number and area. Chlorophyll content decreased with increasing leachate concentration (Fig. 5). The leachate from the Mallam site gave the highest chlorophyll content at the 6.25 mL/L concentration, but compared to the control it was below 50%. Most of the fronds were necrotic, indicating the impact of discharged raw leachate. The few chlorotic fronds observed may have benefitted from the high alkalinity of the leachate, which prevented the dissolution of iron even at the high concentrations detected in the leachates. According to Schuster (2019), iron becomes insoluble at pH values above 6.5 to 6.7. Mackenzie et al. (2003) reported a similar trend on the impact of leachate to *L. minor*. Chlorophylls are susceptible to many chemical or enzymatic degradation reactions. The low content of chlorophyll measured in the fronds could be due to the presence of heavy metals and the high pH of the leachates. The Oblogo landfill leachate had the highest impact with an IC50 of 3.8% (Table 3) which indicates that in the methanogenic phase of the landfill the leachate becomes more toxic to aquatic plants. Surprisingly, the inhibition by

Table 1
pH, conductivity, COD and TOC of leachates from the Tema (TLS), Mallam (MLS) and Oblogo (OLS) landfills in Ghana. Shown are the mean values ± standard deviation (n = 3).

Landfill sites	pH	Conductivity (mS/cm)	COD (mg/L)	TOC (mg/L)
TLS	9.5 ± 0.2	19.5 ± 0.4	215 ± 0.7	6920 ± 0.9
MLS	8.3 ± 0.1	19.7 ± 0.6	541 ± 0.5	900 ± 0.6
OLS	7.8 ± 0.4	18.7 ± 0. 3	110 ± 0.2	350 ± 0.8

Table 2
Heavy metals identified in the leachates of the landfill sites Tema (TLS), Mallam (MLS) and Oblogo (OLS) in Ghana, and the permissible limit defined by the World Health Organization (WHO, 2011). Shown are the mean values ± standard deviation (n = 3).

Heavy metals	WHO, 2011 (mg/L)	Leachates (mg/L)		
		TLS	MLS	OLS
Fe	0.30	42.3 ± 0.4	12.4 ± 0.5	6.55 ± 0.1
Mn	0.50	0.29 ± 0.2	0.16 ± 0.8	0.13 ± 0.6
Zn	3.00	3.88 ± 0.9	0.73 ± 0,9	0.07 ± 0.7
Cr	0.01	6.23 ± 0.5	0.34 ± 0.3	0.16 ± 0.3
Ni	0.02	1.10 ± 0.7	0.43 ± 0.8	0.06 ± 0.8
Pb	0.01	0.20 ± 0.2	0.09 ± 0.5	<0.10
Cu	2.00	<0.20	<0.20	<0.20
Cd	0.03	<0.10	<0.10	<0.10

Table 3
IC50 values for the toxicity of leachates from the Tema (TLS), Mallam (MLS) and Oblogo (OLS) landfill sites in Ghana to duckweed (*Lemna minor*) growth rate and chlorophyll content and to *Daphnia magna* survival. IC50 is the concentration of landfill leachate reducing the endpoint by 50% compared to the control. IC50 is expressed in % of leachate in the test medium. Also shown are the 95% confidence interval (CI) of the IC50 and the R^2, indicating the goodness of fit of the dose-response curve fitted to the data.

	Name of site								
	TLS	MLS	OLS	TLS	MLS	OLS	TLS	MLS	OLS
	Growth rate inhibition			Chlorophyll inhibition			Daphnia inhibition		
IC50	3.5	5.5	3.1	4.6	6.8	3.8	2.8	29.5	10.4
CI	2.6–4.8	4.8–6.3	2.2–5.9	4.4–4.9	6.1–6.9	3.5–4.9	2.8–2.2.9	21.3–41.0	9.8–11.2
R^2	0.99	0.99	0.99	0.99	0.99	0.99	1	0.96	0.99

leachates from the Mallam landfill site, which was also in the methanogenic phase, was the lowest with an IC50 of 6.8% (Table 3). This might be due to the capping of the site which prevented percolation of water through the waste body and hence no further leaching of materials into the sump.

The duckweed toxicity test showed acute/severe toxicity to all the landfill leachate samples IC50 < 9 (Table 3). The Oblogo leachate had the lowest toxicity which indicates toxicity increases with increasing in age of the leachate. The toxicity results obtained correlates to the physico-chemical data, because it can be observed that the COD and TOC increases as toxicity decreases (Tables 1 and 3). The Oblogo leachate has the lowest COD and TOC values which could contribute to its high toxicity to duckweed, because plant needs carbon dioxide to support its growth. Hence, resulting in poor fronds growth and chlorophyll content. However, for metal analysis the trends changed, where the Oblogo leachate with high toxicity has low metal concentrations (Table 2). The Tema leachates showered different trend in relations to metal concentration, in that it recorded the highest concentrations of metals, but even though showered acute toxicity it was lower than the Oblogo leachate. This confirms Clément and Bouvet (1993), that metal concentrations is not the only factor that cause toxicity in *L. minor* in assessment of landfill leachate using the duckweed and this correlates to the results obtained in this research. It can be concluded from the results obtained that organic matter within the leachate is one of the major causes of toxicity. Also, it was reported by Ward et al. (2002), Ammonia in leachate contributes significant amount of toxicity to plants and invertebrates and this could be related to the high toxicity obtained in the leachate samples from the various landfill sites.

3.2.2. Daphnia magna immobilization

The *D. magna* acute toxicity test is one of the fastest and easiest ways of determining the quality of water samples. The leachate from the Tema landfill site caused daphnia immobility at all concentrations (Fig. 6), which indicates that it was more toxic than the other leachates. The high toxicity could be due to the high pH of the leachate (Table 1), which was above the optimum pH for survival, growth and reproduction of *D. magna* (Mahassen et al., 2011).The pH of the other leachates; Mallam and Oblogo, fell within the optimum pH, but also these leachates were toxic to *D. magna* at the two higher concentrations of 50 and 100 mL/L (Fig. 6).

The high toxicity of the leachates could be due to their high conductivity and the presence of heavy metals (Žaltauskaitė and Vaitonytė, 2016). The IC50 values for the immobilization of *D. magna* of the three leachates were Tema - 2.3%, Mallam - 29.5% and Oblogo - 10.4% landfill. The Mallam landfill site had the lowest toxicity compared to the other landfill leachates, which might be due to the capping of this landfill site reducing the leaching of potentially toxic materials. At the high concentrations of 50 and 100% all leachates were inhibitory to *D. magna*, irrespective of the age of the landfill. The trend of toxicity of Daphnia toxicity test to the various leachate samples changed from the duckweed toxicity. Here, the Mallam leachate was more toxic as to the duckweed to which Oblogo leachate was more toxic and this indicates that the physiological make-up of the test organisms contribute largely to the response to toxic substances in the sample (Table 3). The high TOC within the leachates could also contribute to high toxicity, because the high organic matter could result in depletion of oxygen content within the sample there by affecting the survival rate of the Daphnia. The high level of chlorine detected within the Mallam leachate could be one of the contributing factors of the acute toxicity because its presence in water body is very detrimental to the growth and reproduction of Daphnia. The presence of Ammonia in the leachate could be contributing factor to the acute toxicity recorded with Daphnia toxicity, because Ward et al. (2002), reported that Ammonia in leachate contributes significant amount of toxicity to plants and invertebrates.

To establish how far the leachate toxicities differ from each other, the toxicity values where mutually evaluated by one-way analysis of variance (ANOVA, $P < 0.05$). The P-value was 0.409 which indicates that there was no significant difference between the various leachate toxicity values.

The results obtained will help decision makers and environmental experts to better understand the extent of damage to ecosystem when these leachates are released without treatment into the environment.

4. Conclusion and future perspective

The Ghana landfill leachates investigated were highly toxic to both the aquatic organisms used for this study. The high pH, conductivity and heavy metals levels of landfill leachates were the main causes of the toxicity. The age of the landfill site also contributed to the toxicity of the leachate. The leachate from the oldest site (Oblogo) being more toxic to duckweed compared to that from the youngest site (Tema). Leachate from the Tema landfill site was more toxic to *D. magna* and less toxic to *L minor*. The leachate from the Mallam site was not as toxic to the test organisms compared to the other leachates, which could be due to the capping of the site which prevented water from percolating through the waste to continue to leach potentially toxic compounds. To reduce the toxicity of aged landfills, proper decommissioning or capping is needed to reduce the percolation of water through the waste body. Assessing their toxicity to aquatic organisms has shown the urgent need to treat leachates from landfill sites before discharge in surface water. From the results obtained, further research will be carried out in the following area in the near future:

a) to assess the effect of landfill leachate to on-site plants and animals;
b) to detect level of contamination and toxicity of soil samples from close to the landfill sites;
c) to evaluate leachate toxicity from other landfills in Ghana and.
d) to identify and recommend feasible and environmentally friendly methods for waste management and landfill leachate treatment in relations to Ghana conditions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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